1,087,594

PATENT SPECIFICATION 1,087,594

DRAWINGS ATTACHED.

Date of Application and filing Complete Specification: *Oct. 7, 1965.* *No. 42606/65.*

Application made in United States of America (No. 406,102) on Oct. 23, 1964.

Complete Specification Published: Oct. 18, 1967.

Index at Acceptance:—H1 T(1F, 3, 4, 5, 6, 7C1B2, 7C3, 7C6, 8, 9, 10, 11, 14).

Int. Cl.:—H 01 f 27/32.

COMPLETE SPECIFICATION.

Electrical Apparatus.

We, WESTINGHOUSE ELECTRIC CORPORATION, a Corporation organised and existing under the laws of the Commonwealth of Pennsylvania, United States of America, of Three Gateway Center, P.O. Box 2278, Pittsburgh 30, Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates in general to electrical inductive apparatus and more particularly to electrical inductive apparatus having capsulated windings wound from enameled strip or foil conductor.

Effort is continuously being made to reduce the size and weight of electrical inductive apparatus, such as transformers, as well as increase their useful operating life. Transformer size and weight has received particular attention with the increasing demand for dry-type transformers with higher voltage ratings. At voltages of 15KV, or even 7KV, the dry-type transformer which utilizes air and discontinuous solid insulating members for its major insulation becomes extremely large compared with a fluid cooled transformer of the same rating. Accordingly, it is desirable to provide a dry-type transformer which is substantially lighter and smaller than dry-type transformers of the prior art.

The use of cast solid insulation, which has electrical insulating qualities approximately 100 times better than air, is one approach to the size problem. Solid insulation may fail in either of two ways, by "puncture" through the body of the solid material, or by "creep" around the edges of the solid insulation. The resistance of most solid insulation to failure by puncture is far greater than resistance to failure by creep, particularly if the creep path can be contaminated by moisture or conductive particles. It is, therefore, desirable to stress solid insulation only in puncture, with no stressed surfaces which may fail in creep. Cast solid insulation, in contrast to solid insulation applied in discrete members, is continuous around the windings, and has no edges or surfaces subject to creep failure. Thus, cast solid insulation will substantially improve the space factor of a winding. The windings of the transformer may be embedded or capsulated into the cast solid insulation, which eliminates the large creep clearances required in transformers which depend upon air and discontinuous solid members for insulation.

Problems are immediately created, however, when considering capsulating windings in rigid, solid insulation. In order to be successful, the solid insulation must have superior physical properties at elevated temperatures, high thermal conductivity, a very low coefficient of thermal expansion, and excellent crack resistant characteristics. Very rigid insulation systems are usually brittle, they have a high degree of shrinkage, and are poor in crack resistance. If these rigid insulation systems are highly filled with an inert filler to reduce their brittleness and shrinkage and improve their crack resistance, the insulation becomes so viscous that it cannot be poured and handled as a casting resin. Flexible resin systems may be designed with excellent crack resistance, but they have an extremely high coefficient of thermal expansion and are weak at elevated temperatures. Accordingly, it is desirable to provide a transformer having solid, rigid insulation which possesses good physical properties at elevated temperatures, a low coefficient of thermal ex-

pansion, and excellent crack resistant characteristics.

Another problem arises when trying to capsulate electrical windings having the conventional wire-type of conductors. It is difficult to uniformly impregnate the windings with the viscous capsulating material. Any voids produce barriers to heat flow, and produce places for the air to ionize under the high coil layer-to-layer voltages, causing corona with its accompanying radio interference and degradation of insulation. Round, or semi-round, wire conductors, in addition to requiring insulation between coil layers, and turn-to-turn insulation, provide a poor space factor, increasing the size of the winding. Further, simple metallic ducts for cooling purposes may not be utilized to provide paths for cooling fluid, because the winding potential is continually varying across the portion of the winding at which the ducts would be disposed. Any cooling ducts must be formed of a non-conducting material, or the ducts must be formed by removable inserts which are cast into the solid insulation and removed after the insulation has been cured. It is, therefore, desirable to provide a winding having conductors which provide an improved space factor, and which eliminate layer-to-layer voltage stresses found in conventional windings, along with the layer-to-layer insulation, thus reducing the size of the windings and making it unimportant whether the solid insulation completely impregnates the winding. Without layer-to-layer voltage stresses, corona would not be a problem. A solution to these problems is found by constructing the windings of electrically conducting metallic foil or thin strip, which provides an excellent space factor and eliminates layer-to-layer voltage stress and insulation. Further, by utilizing conducting foil or strip, metallic cooling ducts may be utilized, as the winding will be at the same potential across its width where the cooling ducts are disposed, and interleaved turn-to-turn insulation may be eliminated by utilizing foil or strip which has a coating of an electrical insulating material thereon.

It would further be desirable to utilize solid insulation which completely provides all of the electrical insulation required by the winding, and which eliminates all moisture absorbing cellulosic materials. If this construction is provided, the transformer may be operated as a dry-type transformer, and it may have its rating considerably increased when desired by operating the transformer with a fluid coolant. Another advantage in providing the total or complete electrical insulating qualities required by the transformer through a solid insulation system is the fact that the fluid coolant may be chosen strictly for its cooling properties. It would not also have to be an electrical insulator. Although askarel, oil, or SF6 may be utilized, inexpensive coolants such as water could also be utilized. A transformer having windings cast in solid insulation which is impervious to moisture could be submerged directly into a tank of water, which would substantially increase its rating over its dry-type rating. Or, if oil or askarel were used, it would not be necessary to seal the tank as elaborately as transformers of the prior art, because it would not be necessary to maintain the cooling fluid in good electrical insulating condition. Thus, the electrical bushings could be constructed less elaborately and would be less costly.

It is an object of this invention to provide new and improved electrical inductive apparatus utilizing a solid insulation system for encapsulating the electrical windings.

In accordance with the present invention there is provided an electrical inductive apparatus, comprising first and second windings concentrically disposed and coupled inductively by at least one magnetic core and formed of electrically conductive foil or thin strip material, the foil or thin strip material in at least one of said windings being coated with an electrical insulating means, said windings having only one turn per layer, cast solid insulating means encapsulating at least the winding formed of the insulation-coated foil or thin strip material and having substantially the same coefficient of thermal expansion as the winding encapsulated therein, and shielding means disposed between said first and second windings to reduce the voltage stress between them.

Thus, the present invention accomplishes the above-cited objects by forming the electrical windings of conducting strip or foil, such as copper or aluminum. The foil has a coating of insulating enamel disposed on both sides thereof, providing turn-to-turn insulation, which eliminates the necessity of interleaving the winding turns with separate sheet insulation. The electrical windings are capsulated with an epoxy resin system specially formulated to provide a solid, rigid insulation having good physical properties at the maximum operating temperature of the transformer, a low coefficient of thermal expansion, high thermal conductivity, and excellent crack resistant qualities. The crack resistant qualities of the resin system even allows successive winding and casting of the low and high voltage windings sections, if desired, without the necessity of disposing a resilient member between the high and low voltage winding sections.

The winding construction eliminates all moisture absorbing materials, allowing the

transformer to be operated dry, fluid cooled, or buried directly in the earth. The epoxy resin system utilized provides complete electrical and mechanical protection for the coils and eliminates the requirement of bracing the winding sections. The insulation provides complete protection against short circuit stresses, because of the great strength of the insulation system. Since the solid insulation provides the necessary electrical insulation required by the windings, if the transformer is cooled by auxiliary means, the fluid coolant may be selected with only the cooling properties of the coolant in mind, as the coolant will not also have to be an electrical insulator.

Since the windings are formed of conductive strip or foil, the strip or foil will be at the same potential across its width, allowing inexpensive metallic ducts to be inserted in or between the windings, across the width of the winding turns.

For a better understanding of the invention, several preferred embodiment thereof will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a front elevational view of a transformer constructed according to the invention;

Fig. 2 is a side elevation of the transformer shown in Fig. 1;

Fig. 3 is a plan view of the transformer illustrated in Figs. 1 and 2, shown without a casing and end frames;

Fig. 4 is a perspective view of the winding assembly shown in Figs. 1, 2 and 3, illustrating the high and low voltage winding sections and how they are assembled;

Fig. 5 is a perspective view of a cooling duct that may be utilized with the cast winding construction of this invention;

Fig. 6 is a sectional view of the winding assembly, taken along lines VI—VI in Fig. 3;

Fig. 7 is a front elevational view of a transformer illustrating another embodiment of the invention;

Figs. 8, 9, 10 and 11 illustrate steps which may be followed in the construction of the transformer shown in Fig. 7;

Fig. 12 illustrates another embodiment of the invention in which a transformer constructed according to the invention may be operated as a "draw-out" transformer; and

Fig. 13 illustrates another embodiment of the invention in which a transformer is buried directly in the earth.

Referring now to the drawings, and Figs. 1, 2 and 3 in particular, there are shown front and side elevations, and a plan view, respectively, of a transformer 10 constructed according to the invention. In particular, the transformer 10 includes winding assembly 12 disposed in inductive relation with magnetic core portions or sections 14 and 16. The winding assembly 12, in this embodiment of the invention, comprises two sections, a high voltage section 18 and a low voltage section 20. The high and low voltage winding sections 18 and 20, respectively, may be wound in separate operations and assembled concentrically, with the low voltage winding section 20 being disposed within the opening formed in the high voltage winding sections 18. Fig. 4 illustrates the two winding sections, 18 and 20, in a perspective view, illustrating how one winding section is disposed concentrically with the other.

The magnetic core sections 14 and 16 are constructed in any conventional manner, such as by assembling and banding wound magnetic cores through the opening formed in the low voltage winding section 20, as described in British Patent Specification No. 570730, or as shown in Figs. 1 and 2, the magnetic core may be constructed by stacking individual laminations 26 of a magnetic material in a superimposed manner, and securing them in end frames 22 and 24. If the magnetic core sections 14 and 16 are constructed of stacked individual laminations 26, which may be a magnetic material such as single or multiple grain oriented silicon steel, the laminations 26 are arranged to form a pair of rectangles each having two leg portions and two yoke portions. Before closing the rectangles a leg portion of each rectangle is disposed through the opening formed in the low voltage winding section 20, and the windows of the stacked rectangles allow the high and low voltage winding sections 18 and 20 to be closely inductively coupled with the magnetic core sections 14 and 16.

Figure 6 is a sectional view of winding assembly 12 showing the high and low voltage winding sections 18 and 20, respectively, in greater detail. In this embodiment of the invention, the high voltage winding section 18 has strip or foil conductor 30 wound concentrically upon a tube 32. The winding is then capsulated in a rigid, solid insulation system 34, with the winding leads being brought out through the solid insulation at terminals 36 and 38, as shown in Figs. 1 and 2. The tube 32 may be formed of laminted plastics or resin or any other electrical insulating structure which is free of cellulosic materials.

The strip or foil conductor 30, which is formed of a conducting metal, such as copper or aluminum, has a coating of insulating enamel 40 disposed thereon. The insulating enamel 40 may be formed of a resin, such as those of an epoxy type, and it provides the necessary turn-to-turn insulation. By utilizing strip conductor instead of wire-type conductor, there is no wasted

space, resulting in a winding having the best possible space factor, and it also eliminates the need for layer insulation, which is required in windings using a wire-type conductor. Since the voltage between adjacent turns is always very low in a strip or foil wound winding, the capsulating insulation 34 need not impregnate all of the voids within the winding itself. Corona will not be created at the low voltages which exist between individual turns. Thus, an enamel coated foil wound winding reduces the winding size to an absolute minimum, makes interleaving separate sheets of turn-to-turn insulation unnecessary, eliminates the need for layer insulation, and eliminates the problem of completely impregnating the winding.

In this particular embodiment of the invention, the transformer 10 is to be air cooled. Since the transformer will not be immersed in a cooling fluid, the low voltage winding section 20 need not be capsulated in the solid insulation system, resulting in a further reduction in the size and weight of the transformer 10.

The low voltage winding section 20 is formed of strip or foil conductor 42, which may be copper, aluminum, or any other suitable conductor of electricity, with electrical insulation 44 disposed between the individual turns. Electrical insulation 44 may be an enamel insulating material disposed on the strip itself, or, as shown in Figure 6, may be a separate sheet of non-cellulosic material, such as polyethylene terephthalate resin, which is interleaved with the conducting strip 42 at the time the low voltage winding section 20 is wound. The insulation 44 may project past the outer edges of the strip 42, as shown at 46. An insulating tape, such as glass tape 48, may be wound over the outer surfaces of the low voltage winding section 20. The low voltage winding assembly has electrical leads 50 and 52 attached to the strip conductor 42.

The transformer 10 may be housed in a suitable casing 54, as shown in Figs. 1 and 2, with the high voltage and low voltage leads being connected to external electrical conductors (not shown) through the bottom of the casing 54, or through suitable terminals disposed on the casing 54 itself.

Since the transformer 10 depends upon air circulation for its cooling, the casing 54 should contain openings or louvers to allow free air circulation into and out of the casing 54. Casing 54 could be eliminated in the event the transformer 10 were to be disposed in a special room.

To further aid in the air cooling of the transformer 10, cooling ducts 60 may be disposed through the high and low voltage winding sections 18 and 20, respectively, to allow air to flow in close proximity with the winding turns. The use of strip or foil windings greatly simplifies the problem of providing cooling ducts. With wire type conductors, the winding across its width is at different potentials, requiring the ducts to be moulded into the solid insulation itself by removable inserts, which are removed after the solid insulation is cured, or by using ducts formed of an electrical insulating material. The strip or foil conductors permit an inexpensive metallic duct to be used, such as the aluminum extrusion shown in Fig. 5, which greatly facilitates heat transfer from the windings to the cooling medium in the ducts. The projecting legs 62 of the duct 60 may be disposed adjacent the conducting foil and its insulation when the winding is being wound, without danger of short circuits and circulating currents. The air in the cooling ducts will be heated by the windings, causing the air to rise and start a natural circulation, with heated air leaving the ducts at the top and cool air entering the ducts at the bottom. The bottom 66 of the casing 54 shown in Fig. 2, may be corrugated and elevated slightly from the floor by member 68, to permit free entry of cool air.

In order to reduce or substantially eliminate the voltage stress applied to the air between the high and low voltage winding sections 18 and 20, respectively, permitting the high and low voltage winding sections 18 and 20 to be closely coupled in a concentric manner with a minimum of spacing therebetween, the encapsulated high voltage winding section 18 is coated with a conducting varnish or paint as indicated at 70 in Fig. 4. The conducting varnish 70 may be of the type having a suitable binder in which carbon particles are intermixed, with the conducting varnish having a resistivity in the range of 25,000 ohms/square. In order to terminate the conducting varnish with a minimum of stress, a stress grading paint 72 may be applied to the edge of the conducting varnish 70, overlapping the conducting varnish 70 at 74 for a short distance, such as .5 inches. The stress grading paint 72 has a voltage dependent resistivity, with the resistivity of the coating automatically assuming the most desirable value across its surface. Stress grading paints containing particulated silicon carbide whose content is approximately 25% of the volume of the coating, intermixed with a suitable resinous binder, have been found to give excellent results.

The rigid, thermosetting, solid cast insulation system 34, shown in Fig. 6 must have a coefficient of thermal expansion tailored to be compatible with the strip conductor 30 that it is to capsulate. Further, the insulation system 34 must have excellent characteristics at the elevated temperatures at which

the transformer is designed to operate, high thermal conductivity, and it must have excellent crack resistant characteristics. A rigid, castable thermosetting insulation system having a low coefficient of thermal expansion and crack resistant characteristics is difficult to achieve. Rigid systems, unless very highly filled, are usually brittle, have a high degree of shrinkage, and are poor in crack resistance. If these rigid systems are highly filled to reduce their brittleness and shrinkage and improve their crack resistance, the resulting system is usually too viscous to pour and may not be handled as a castable material. Flexible resin systems may be designed with excellent crack resistance, but they have an extremely high coefficient of thermal expansion and are very weak at elevated temperatures.

A rigid, thermosetting resin system which successfully matches the coefficient of expansion of aluminum (23.6 micro-inches, per-inch per °C), has excellent high temperature and crack resistant characteristics, high thermal conductivity, and is castable, has the following composition:

Material	Parts by Weight
Epoxy Resin	
Epoxy Equivalent 180—210 (Jones-Dabney "Epi-Rex 510")	100
Hexahydrophthalic Anhydride ...	80
Dimethyl Propylamine (Rohm & Haas DMP-10) ...	0.18
Pigment CR_2O_3	5.4
Particulated Beryllium Aluminum Silicate	506.0
Anhydrous Colloidal Silica (John L. Cabot "CAB-O-SIL")	28.0

The Hexahydrophthalic Anhydride is the curing agent, the Dimethyl Propylamine is the accelerator which controls the curing time, the Beryllium Aluminum Silicate is the filler which minimizes shrinkage, lowers the coefficient of thermal expansion of the system, provides excellent thermal conductivity, and produces the crack resistance, and the Anhydrous Colloidal Silica is a thixotropic agent which prevents setting of the filter.

A modification of this resin system which allows the resin to be adapted to production line techniques by allowing the resin component and curing components to be mixed at the casting temperature of 100°C when the casting mixture is required, is as follows:

Material	Parts by Weight
Epoxy Resin	
Epoxy Equivalent 180—210 ...	100
A mixture of 85% hexahydrophthalic anhydride and 15% tetrahydrophthalic anhydride	72
Hexahydrophthalic anhydride ...	8
Particulated Beryllium Aluminum silicate	503
Anhydrous Colloidal Silica	18.0
A product of equimolar mixture of triethanolamine titanate and trihexylene glycol biborate ... ... (See British Patent Specification No. 903,634 assigned to the same assignee as the present application).	0.50

The modified resin system produces the same results as the former resin system, and allows the material to be stored at casting temperatures for long periods of time and still produce a resin system which is castable.

In summary, the dry-type transformer shown in Figs 1—6 utilizes coated foil or strip conductor, cast solid thermosetting insulation, and stress grading paint in a manner which produces a high voltage, high impulse, corona free structure which is substantially smaller and lighter than prior art transformers of equivalent voltage and power ratings. For example, a 167 KVA transformer having a 15KV insulation system constructed according to the invention weighs 1700 pounds. The conventional dry-type transformer of the prior art, which depends upon air and discontinuous solid members for its insulation, weighs approximately 3200 pounds. The conventional dry-type transformer, which utilizes solid insulation but uses conventional wire type conductor weighs approximately 2200 pounds. Thus, a very substantial reduction in weight has been made in dry-type transformers, and the size reduction is in approximately the same ratio.

The type of construction shown in Figs. 1—6, and hereinbefore described, may be extended to provide transformers suitable for disposing underground for underground distribution systems, and for fluid cooled transformers. The modification merely involves capsulating the low voltage winding with the same cast, solid insulation system used to cast the high voltage winding of the transformer shown in Figs 1—6.

Fig. 7 is a front elevation of a transformer 80 which has a winding assembly 82 disposed in inductive relation with magnetic core sections 84 and 86, all disposed within

a suitable metallic casing or enclosure 88 (shown in section). A fluid 89 is disposed in the enclosure 88 to surround and cool the winding assembly 82 and magnetic core sections 84 and 86. The fluid 89 may be a gas, such as SF6, or a liquid such as askarel, oil, or water. Since a solid insulation system completely insulates the winding assembly 82, the insulating fluid may be chosen without regard to its electrical insulating properties. Thus, since the fluid is chosen only for its cooling qualities, no compromise need be made, and excellent cooling mediums, such as water, may be utilized freely. The transformer 80 may be operated without auxiliary cooling, if desired, depending upon air for cooling, at a certain rating, and then, if required, its rating may be substantially increased by placing the transformer in an enclosure and filling the enclosure with a fluid coolant. If a transformer has both its high and low voltage windings capsulated in cast, solid insulation, and its rating as a dry-type transformer is assumed to be 100%, its capacity would be increased 40% if oil cooled, and 125% if water cooled.

One suitable method of constructing a transformer 80 in which both the high and low voltage windings are completely capsulated in cast, solid insulation, is shown in Figs. 8—11. In Fig. 8, a low voltage winding 90 of conductive strip or foil, having an enameled electrical insulating coating disposed thereon, is wound on an insulating tube 92, formed of the same cast insulation that is used to capsulate the windings, or of any other suitable electrical insulating material. After the low voltage winding 90 has been wound, having the desired number of turns 94 separated by the enamel coating, and electrical leads 96 and 98 attached thereto, the winding 90 and tube 92 are placed in a mould and rigid, cast, solid insulation 100 is cast around the low voltage winding 90, as shown in Fig. 9. This may be the same solid insulation system hereinbefore described relative to Figs. 1—6. As shown in Fig. 10, a high voltage winding 102 is then wound directly upon the cast solid insulation 100, with high voltage leads 104 and 106 extending therefrom. This assembly is then placed in a mold and solid insulation 110 is cast around the high voltage winding 102. A conductive shield (not shown) is embedded in the cast insulation 109 between the low voltage winding 90 and high voltage winding 102 at the time of casting, in order to reduce the voltage stress between the winding sections.

An outer waterproofing coating 111 may be applied to the winding assembly after insulation 110 has been cast, if the transformer 80 is to be directly immersed in water. Filled resins when submerged in water may absorb small quantities of water over a long period of time. In order to prevent this gradual absorption, an unfilled resin, such as epoxy, or systems such as those containing butadiene-styrene or silicone rubber, may be used to coat the assembly.

The insulation system hereinbefore described makes the successive casting techniques shown in Figs. 8—11 possible. With other resin systems, in order to prevent cracking of the insulation between the high and low voltage winding sections due to thermal cycling, it is necessary to cast the high and low voltage windings separately and join them with a flexible intercoil material to absorb the stresses. The insulation system described herein, however, has excellent qualities at the temperature at which the transformer is to operate, a coefficient of thermal expansion that matches the coefficient of thermal expansion of the capsulated conductors, high thermal conductivity, and excellent crack resistance. These qualitities allow successive casting techniques shown in Figs. 8—11 without any subsequent cracking between the high and low voltage windings.

Metallic ducts, as hereinbefore described and shown in Fig. 5, may be disposed in the winding structure, if desired.

Referring again to Fig. 7, since the fluid 89 does not have to possess electrical insulating qualtities, the high voltage bushings 112 and 114, connected to electrical leads 104 and 106, respectively, and the low voltage bushings (not shown), need not provide an elaborate seal. Thus, the construction of the bushings may be greatly simplified, reducing their cost.

If the transformer 80 is utilized liquid cooled, such as by water, the water may have a rust inhibitor added thereto to prevent the magnetic core from rusting, or the magnetic core may be coated with a waterproofing material, such as a fluidized coating of epoxy resin. Other parts, such as end frames, may be constructed of aluminum.

To increase the efficiency of the heat transfer from the surface of the winding assembly 82 of transformer 80, if liquid cooled, the surface 120 of the encapsulated winding assembly 82 shown in Fig. 7 may be roughened by sandblasting, polishing with an abrasive, or any other suitable means, to produce a surface which creates nucleate boiling. Nucleate boiling occurs from small cavities or depressions of the surface 120 of the winding assembly 82, when the surface of the winding assembly reaches the boiling point of the liquid coolant, and the liquid coolant is below its boiling point. During nucleate boiling, minute bubbles are created and released from the plurality of cavities or depressions, which greatly increases the heat transfer from the surface

to be cooled. The surface cavities must be very small in order to be good bubble sites, with the diameter of active bubble sites falling in the size range of 0.05 to 5 mils.

As hereinbefore stated, transformers having capsulated high and low voltage winding sections may be operated dry, as well as with fluid cooling means. Fig. 12 illustrates an embodiment of the invention wherein the transformer is operated dry. More particularly, Fig. 12 shows a transformer 130 mounted on a carriage 136 having wheels 138 disposed thereon, which are supported and guided by rails 140. Transformer 130 is of the dry-type, having a core structure 134, a capsulated winding assembly 132, including high and low voltage winding sections having leads 148 and 142, respectively. Shielding means for reducing the voltage stress between the high and low voltage sections are provided as described in connection with Figs. 4 or 10. The leads 148 and 142 are insulated and may extend through strengthening member 154 and terminate in the bayonet type connectors, 155 and 157, respectively. High voltage leads 148 may terminate in a male portion of bayonet connector 155, with conductor 150 making contact with an internal line conductor in portion 152 of bayonet connector 155. Low voltage leads 152 may terminate in the female portion of bayonet connector 157, with conductor 144 extending from portion 146 of bayonet connector 157, making contact with an internal conductor in bayonet connector 157. The transformer 130 is thus completely "dead front", as the windings are capsulated, the electrical leads are insulated, and the connections to external conductors are completely enclosed. There is no exposed live terminals. A casing is not required, nor are conventional electrical insulating bushings required. The transformer 130 may be operated "draw out", allowing the primary and secondary electrical circuits to be completed or broken, when desired, by mere horizontal movement of the transformer. Thus, maintenance people would not have to work on the transformer with any live parts exposed, and could easily disconnect the transformer from the electrical power source to connect it to the electrical power source, in complete safety.

The transformer construction described herein, wherein the windings of the transformer are completely capsulated in moisture and corrosion resistant solid insulation, is ideal for being disposed directly in the earth, for use with underground distribution systems. The disposition of the transformer in the earth, however, results in a considerable derating of the transformer due to the problem of carrying heat rapidly away from the transformer, particularly in dry earth. Elaborate vaults and auxiliary surface coolers have been resorted to in some instances, but they are costly, and the appearance of the surface coolers reduces the advantage of disposing the transformer underground.

An embodiment of this invention which solves this problem, is shown in Fig. 13. More particularly, Fig. 13 illustrates a dry-type transformer 160 constructed according to the invention, in which the winding assembly 162, disposed in inductive relation with a magnetic core 164, is completely capsulated in cast solid insulation, as hereinbefore described. Shielding means for reducing the voltage stress between the high and low voltage sections are provided as described in connection with Figs. 4 or 10. High voltage leads 166 and 168 are insulated, and make waterproof connections 202 with the power leads 204 and 206 from the primary source. Low voltage leads 170 and 172 are also insulated and make waterproof connections 200 with the secondary or load service conductors 171 and 173.

The transformer 160 is disposed in a hole 179 dug in the earth 180, and then a large, heavy gauge, plastics or rubber bag 182 is placed in the hole 179 to cover the top and at least a portion of the sides of the transformer 160. As shown in Fig. 13, the plastics bag will conform to the outline of the transformer 160 and be in close thermal communication therewith. The bag 182, which may be made of high density, linear polyethylene having a wall thickness of approximately 10 mils, is then filled with a mechanical supporting means or filler 184, such as sand or gravel, and is then filled with water. The weight of the filler 184 and especially the water, will cause the bag 182 to very closely conform to the winding assembly 162 and magnetic core 164. The bag is then closed and the hole 179 is backfilled with earth 186. The mass of the water in the bag 182, combined with the relatively good heat transfer through the walls of the plastics interface of the bag 182, will result in a transformer surface temperature only a few degrees above that of the surrounding water. The bag 182 is made large enough to prevent water from reaching its boiling point, and thus provide a transformer installation which may operate without derating, and which has a great overload capacity. The cost of the heat sink (the filled bag 182) is low, and yet provides an effective, permanent heat sink.

The water should remain in the bag for many years. However, a pipe 190 having a suitable cap may be disposed to enter the bag 182 through a closely conforming waterproof opening, whereby water may be added at periodic intervals if desired.

Thus, there has been shown and des-

cribed a new and improved transformer construction which may be operated dry, fluid cooled, or disposed underground. If operated as a dry-type transformer, it possesses many advantages over conventional dry-type transformers in being significantly smaller and lighter in weight, and more reliable. At voltage levels in the 15KV class, a dry-type transformer constructed according to the invention may be up to 50% lighter than conventional dry-type transformers.

If operated as a fluid cooled transformer, it is able to use the most efficient coolant, even water, without regard to its electrical insulating qualities. The cast, rigid, solid, thermosetting insulation system utilized in this invention, provides complete electrical and mechanical protection for the windings. The coolant is not required to add any additional electrical insulating qualities to the system.

The construction of a transformer of this invention allows it to be buried directly in the earth without expensive vaults or surface coolers, for use with underground distribution systems. By utilizing a simple, inexpensive heat sink, as described herein, the transformer may be operated underground without de-rating and with a substantial overload capability.

The invention has many further advantages, such as the fact that with conductive strip or foil windings, complete impregnation of the winding structure is not required. There are no layer-to-layer voltages present in strip or foil wound coils, thus, conductor insulation need withstand only the low turn-to-turn voltages. Corona is, therefore, not a problem, and the elimination of layer insulation further reduces the size and cost of the windings. Still further, the strip or foil windings will withstand high magnetic forces, such as those exerted upon electrical windings during short circuit conditions, without damage. Coil bracing is also eliminated, as the rigid solid insulation system provides the necessary mechanical support. The enameled insulation disposed on the strip eliminates the need for intervleaving a separate piece of insulation with the strip at the time of winding, providing a low cost winding having an excellent space factor.

Although a single phase transformer has been shown and described herein, it will be obvious that a polyphase transformer may be constructed using the invention which will have all of the benefits and advantages enumerated herein.

WHAT WE CLAIM IS:—

1. Electrical inductive apparatus, comprising first and second windings concentrically disposed and coupled inductively by at least one magnetic core and formed of electrically conductive foil or thin strip material, the foil or thin strip material in at least one of said windings being coated with an electrical insulating means, said windings having only one turn per layer, cast solid insulating means encapsulating at least the winding formed of the insulation-coated foil or thin strip material and having substantially the same coefficient of thermal expansion as the winding encapsulated therein, and shielding means disposed between said first and second windings to reduce the voltage stress between them.

2. Inductive apparatus as claimed in claim 1, wherein the cast solid insulating means encapsulates both the first and second windings.

3. Inductive apparatus as claimed in claim 1 or 2, wherein said shielding means comprises silicon carbide paint.

4. Inductive apparatus as claimed in any of the preceding claims, comprising at least one cooling duct disposed in at least one of said windings.

5. Inductive apparatus as claimed in any of the preceding claims, wherein said cast solid insulating means comprises thermosetting epoxy resin and filler material.

6. Inductive apparatus as claimed in claim 5, wherein said filler material comprises beryllium aluminum silicate.

7. Inductive apparatus as claimed in any of the preceding claims, comprising a casing, the first and second windings and the core or cores being disposed within the casing, and fluid coolant means disposed within the said casing for cooling the windings and the core or cores.

8. Inductive apparatus as claimed in claim 7, wherein said cast solid insulating means has a rough outer surface with surface cavities of size 0.05 to 5 mils so as to increase the heat transfer from said cast solid insulating means to said fluid coolant means.

9. Inductive apparatus as claimed in claim 7 or 8, wherein said fluid coolant means is water.

10. Inductive apparatus as claimed in any of the preceding claims, comprising electrical leads extending from said first and second windings, and moisture proof electrical insulator connector means, said electrical leads from said first and second windings being electrically insulated and connected to primary and secondary electrical conductors through said moisture proof electrical insulating connector means.

11. Inductive apparatus as claimed in any of claims 1 to 9, comprising a transformer for connection to primary and secondary electrical conductors through connector means, the transformer being disposed on a carriage which through horizontal movement will make and break the

electrical connections between the transformer and the primary and secondary electrical conductors.

12. Inductive apparatus as claimed in claim 10, comprising an underground transformer for connection to underground primary and secondary electrical conductors through said connector means, and a heat sink for cooling said inductive apparatus disposed underground in thermal communication with said inductive apparatus.

13. Inductive apparatus as claimed in claim 12, wherein said heat sink comprise a bag containing a cooling liquid and filler material.

14. Inductive apparatus as claimed in claim 13, wherein said heat sink comprises a plastics bag containing water and the filler material.

15. Electrical inductive apparatus comprising a transformer substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

For the Applicants:
SANDERSON & CO.,
Chartered Patent Agents,
97, High Street,
Colchester, Essex.

Abingdon: Printed for Her Majesty's Stationery Office, by Burgess & Son (Abingdon), Ltd.—1967.
Published at The Patent Office, 25 Southampton Buildings, London, W.C.2
from which copies may be obtained.

1087594 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1.

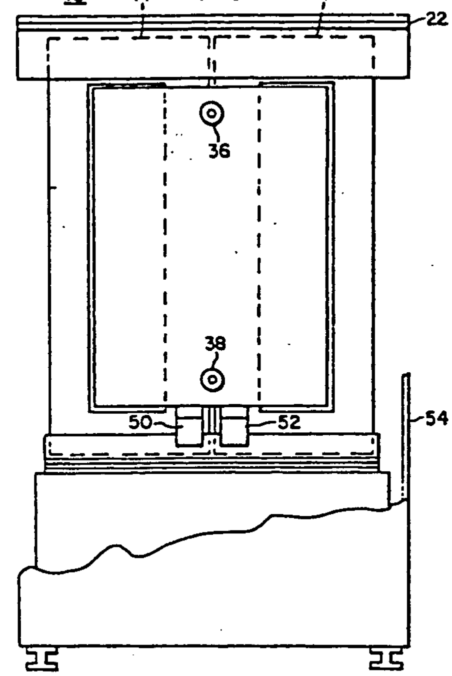
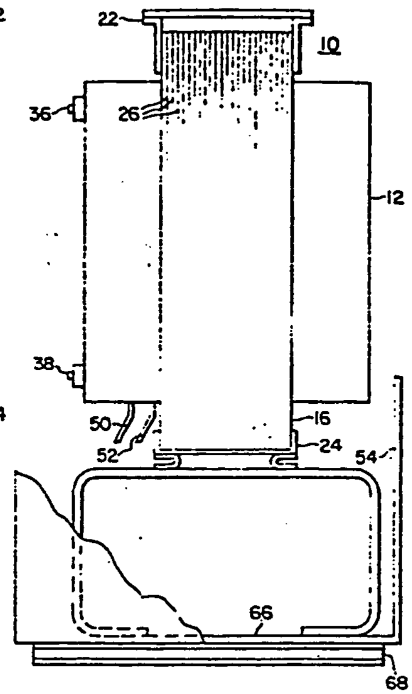


FIG.2.



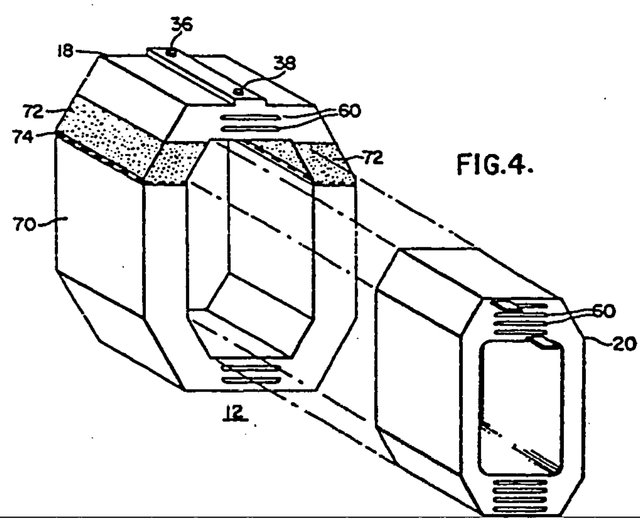


FIG.4.

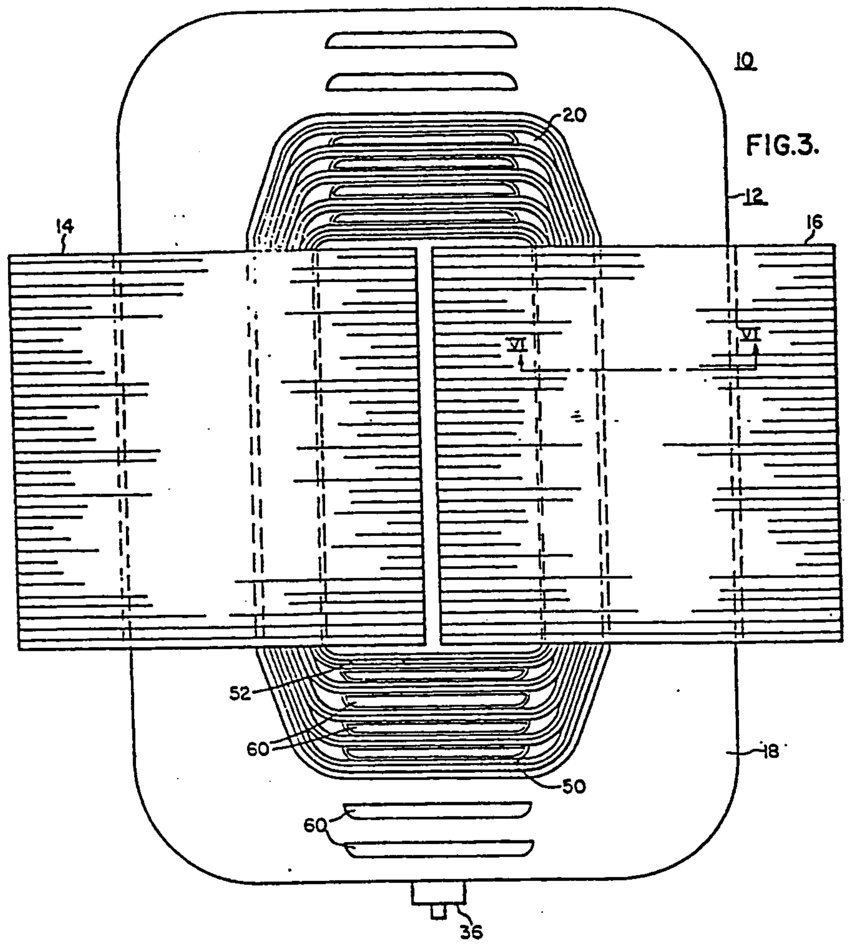


FIG.3.

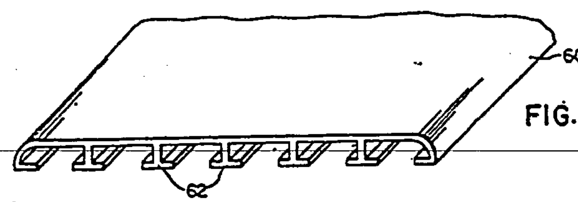


FIG.5.

1087594 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 2 & 3

IG.3.

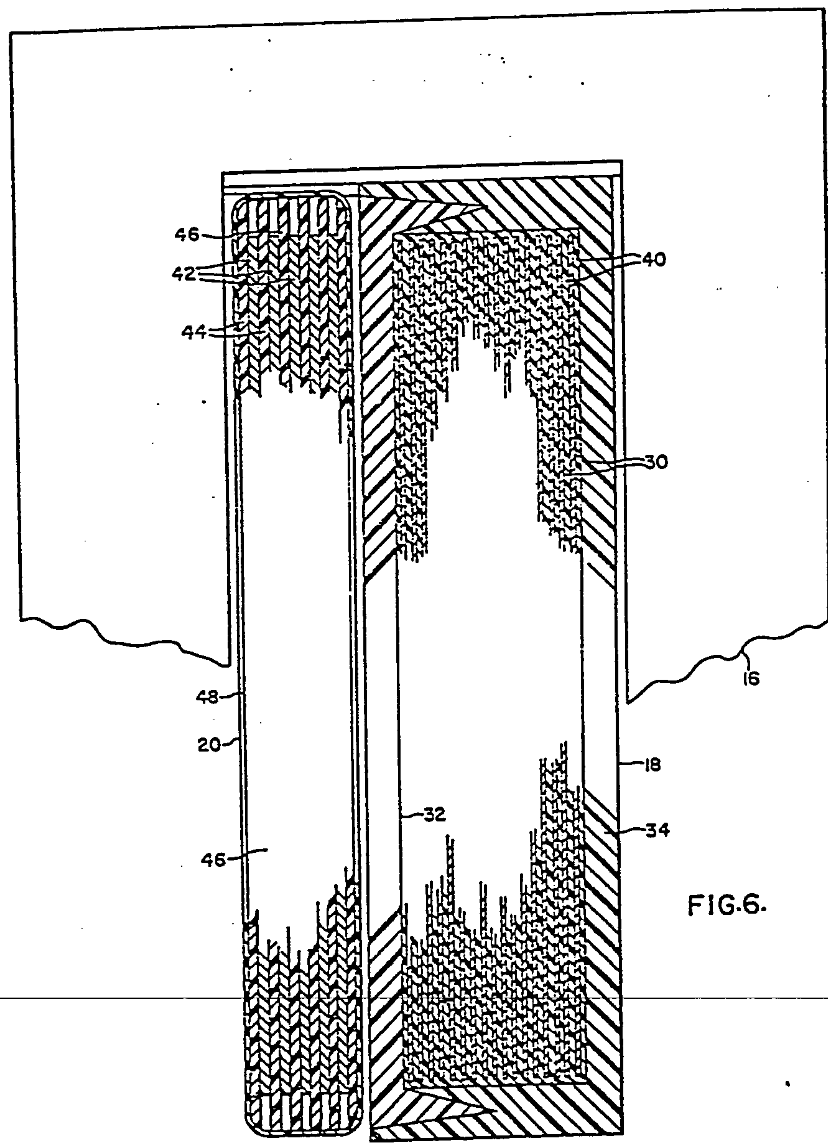


FIG.6.

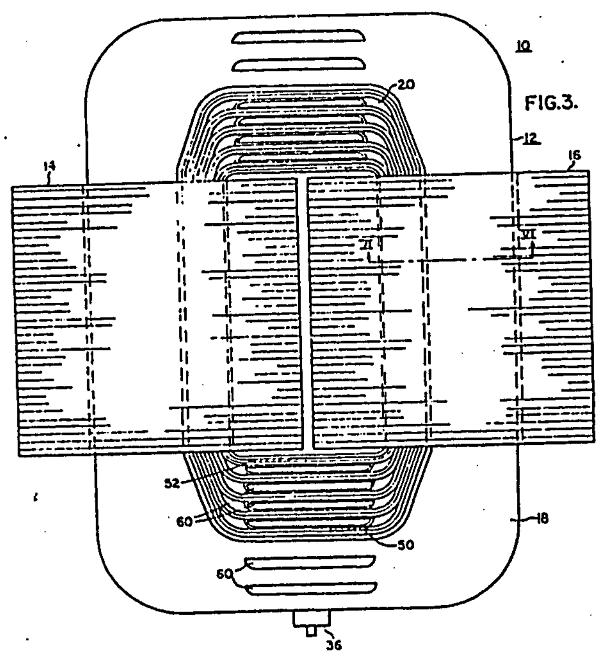


FIG.3.

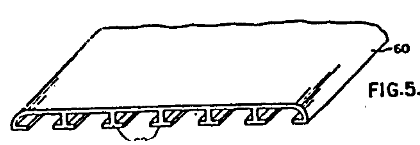


FIG.5.

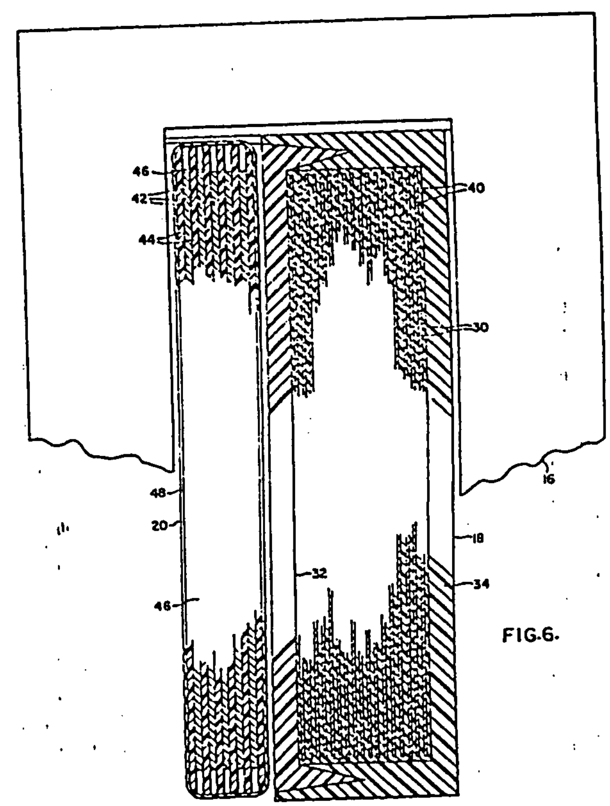


FIG.6.

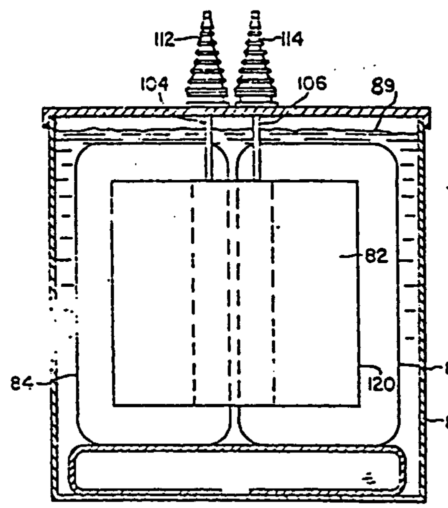


FIG.7.

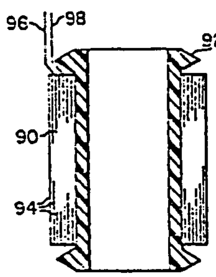


FIG.8.

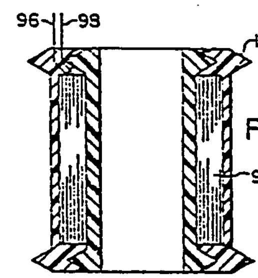


FIG.9.

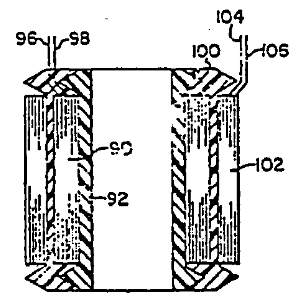


FIG.10.

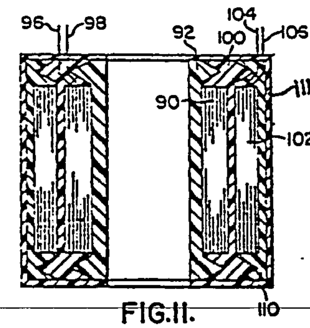


FIG.11.

1087594 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 4 & 5

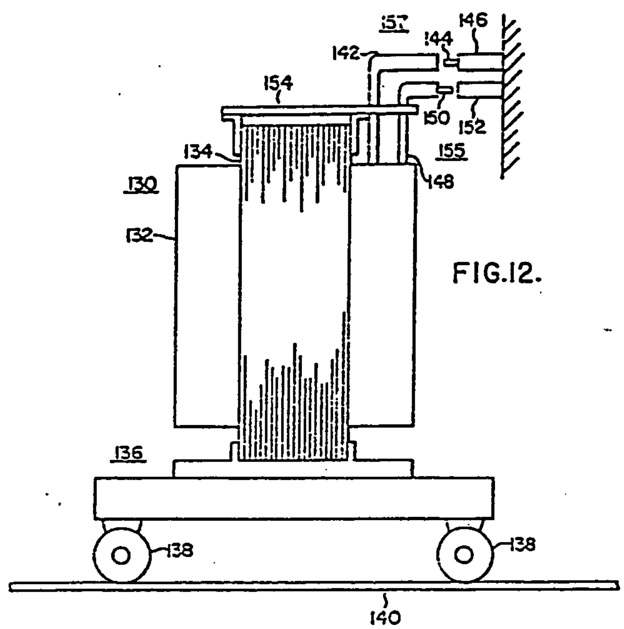


FIG.12.

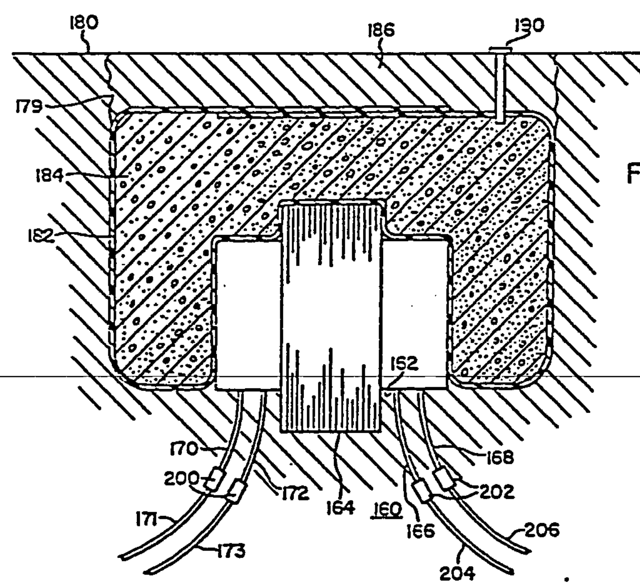


FIG.13.

1087594 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 4 & 5

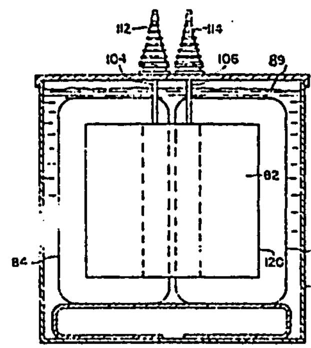


FIG.7.

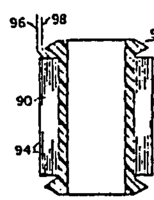


FIG.8.

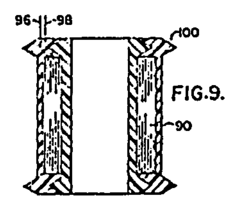


FIG.9.

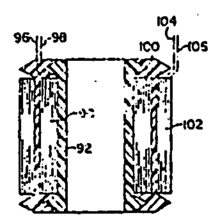


FIG.10.

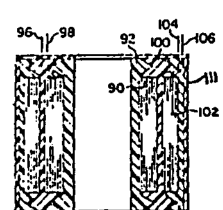


FIG.11.

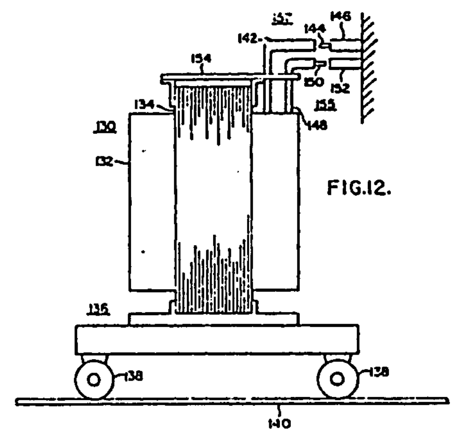


FIG.12.

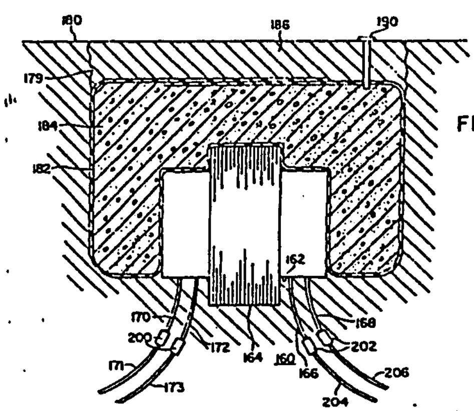


FIG.13.